Universidad de Lima

Facultad de Ingeniería y Arquitectura

Carrera de Ingeniería Industrial

ENVIRONMENTAL IMPACT ASSESSMENT OF FLEXIBLE FOOD PACKAGING

Tesis para optar el Título Profesional de Ingeniero Industrial

Nathalie Katherine Bittrich Vargas

Código 20180244

Marcela Ines Ruiz Mogollón

Código 20172604

Asesor

Rosa Patricia Larios-Francia

Lima – Perú

Setiembre de 2022

VOLUME 19 ISSUE 1

The International Journal of

Environmental Sustainability

Environmental Impact Assessment of Flexible Food Packaging

NATHALIE KATHERINE BITTRICH, MARCELA INES RUIZ MOGOLLÓN, AND ROSA PATRICIA LARIOS-FRANCIA

COMMON GROUND

ONSUSTAINABILITY.COM

THE INTERNATIONAL JOURNAL OF ENVIRONMENTAL SUSTAINABILITY
https://onsustainability.com
ISSN: 2325-1077 (Print)
ISSN: 2325-1085 (Online)
https://doi.org/10.18848/2325-1077/CGP (Journal)

First published by Common Ground Research Networks in 2022
University of Illinois Research Park
60 Hazelwood Drive
Champaign, IL 61820 USA
Ph: +1-217-328-0405
https://cgnetworks.org

The International Journal of Environmental Sustainability is a peer-reviewed, scholarly journal.

Common Ground Research Networks, a member of Crossref

PEER REVIEW
Articles published in *The International Journal of Environmental Sustainability* are peer reviewed using a two-way anonymous peer review model. Reviewers are active participants of the On Sustainability Research Network or a thematically related Research Network. The publisher, editors, reviewers, and authors all agree upon the following standards of expected ethical behavior, which are based on the Committee on Publication Ethics (COPE) Core Practices. More information can be found at https://cgnetworks.org/journals/publication-ethics.

ARTICLE SUBMISSION
The International Journal of Environmental Sustainability publishes biannually (June, December).
To find out more about the submission process, please visit https://onsustainability.com/journals/call-for-papers.

ABSTRACTING AND INDEXING
For a full list of databases in which this journal is indexed, please visit https://onsustainability.com/journals/collection.

RESEARCH NETWORK MEMBERSHIP
Authors in *The International Journal of Environmental Sustainability*
are members ofthe On Sustainability Research Network or a thematically related Research Network. Members receive access to journal content. To find out more, visit https://onsustainability.com/about/become-a-member.

SUBSCRIPTIONS
The International Journal of Environmental Sustainability
is available in electronic and print formats. Subscribe to gain access to content from the current year and the entire backlist.
Contact us at cgscholar.com/cg_support.

ORDERING
Single articles and issues are available from the journal bookstore at https://cgscholar.com/bookstore.

HYBRID OPEN ACCESS
The International Journal of Environmental Sustainability
is Hybrid Open Access, meaning authors can choose to make their articles open access. This allows their work to reach an even wider audience, broadening the dissemination of their research. To find out more, please visit https://cgnetworks.org/journals/hybrid-open-access.

Environmental Impact Assessment of Flexible Food Packaging

Nathalie Katherine Bittrich Vargas,[1] Universidad de Lima, Peru
Marcela Ines Ruiz Mogollón, Universidad de Lima, Peru
Rosa Patricia Larios-Francia, Universidad de Lima, Peru

Abstract: The impacts of environmental pollution are potentially irreversible and have become a major concern for society. Faced with this reality, the purpose of this study is to identify what type of flexible packaging material used in the food industry creates less pollution. The Leopold Matrix was employed to quantitatively assess the life cycle of plastic and paper packaging, using information from various scientific articles and peer-reviewed indexed journals. The interactions between physical, biological, and socioeconomic elements were established for each action in the life cycle of the packages. The results showed that flexible plastic packaging pollutes 16 percent more in the physical aspect concerning soil and water pollution than paper packaging, which has a more significant impact on air pollution. Regarding the biological aspect, plastic pollutes 63 percent more than paper in terms of damage to flora and fauna. Finally, on the socioeconomic level, paper poses a greater health risk for human beings owing to the emission of gases in its production, whereas plastic packages contribute more to the economy for being an extensive industry.

Keywords: Life Cycle, Leopold Matrix, Environmental Impact, Plastic, Paper and Flexible Food Packaging

Introduction

Nowadays, a primary focus of society is the reduction of environmental pollution, mostly generated by mass production industries, which rank third among industries with the largest amount of greenhouse gases emissions (Geyer, Jambeck, and Law 2017). In this case, it has been detected that the plastic packaging production industry creates a major environmental impact (Figure 1).

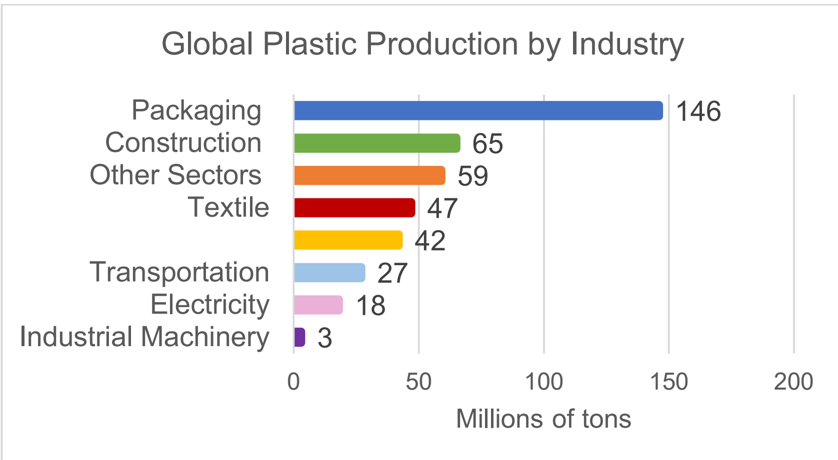

Figure 1: Global Plastic Production by Industry
Source: Tiseo 2017

[1] Corresponding Author: Nathalie Katherine Bittrich Vargas, Carrera de Ingeniería Industrial, Av. Javier Prado Este 4600, Universidad de Lima, Lima, 15023, Peru. email: 20180244@aloe.ulima.edu.pe

The International Journal of Environmental Sustainability
Volume 19, Issue 1, 2022, https://onsustainability.com

ISSN: 2325-1077 (Print), ISSN: 2325-1085 (Online)
https://doi.org/10.18848/2325-1077/CGP/v19i01/39-61 (Article)

Certainly, the food industry is one of the main industrial sectors that consume different types of plastic packaging for protecting and preserving food from elements such as oxygen, smells, and microorganisms, thus ensuring product quality. Depending on the type of packaging material and the technologies used, products of different characteristics can be preserved (Ortega Leyva 2020).

However, a point of uncontrolled plastic consumption has been reached, originating garbage patches in rivers, oceans, and on land owing to debris collection and waste accumulation in landfills and on the streets (United Nations 2018). Therefore, the new green trend has greatly impacted the companies and consumers, as it demands that production processes and products do not exert a negative impact on the environment (U.S. Environmental Protection Agency, n.d.). In response to these environmental challenges, food companies have modified their packaging under the concept of sustainable development, often favoring biodegradable plastic packaging (United Nations 2018).

The United Nations Brundtland Commission (1987) defined sustainability as meeting the needs of the present without compromising the ability of future generations to meet their own needs (United Nations Brundtland Commission 1987). On the other hand, biodegradable polymers are materials, whose molecular structure can change in the presence of environmental agents and break down into simpler or minor substances such as water, carbon dioxide, and biomass that the environment can assimilate (Labeaga 2018). Nevertheless, the trend to use biodegradable plastic packages has not had the expected impact on society or the environment, because many of them do not meet the standards or characteristics necessary to preserve food. These packages do not fully decompose and even emit up to 50 percent of volatile solids and hazardous chemical substances. In addition, biodegradable packaging may take several years to decompose or need proper treatment in special plants to be eliminated completely (Cenergia 2020).

According to the data collected by Euromonitor (2020), a consumption trend was identified regarding the main materials to produce flexible food packaging in 2020. Using the Pareto Chart (Figure 2), it was determined that plastic consumption accounts for 80 percent of the overall packaging consumption. However, a tendency to use paper packaging has also been identified, representing 8.02 percent in 2020.

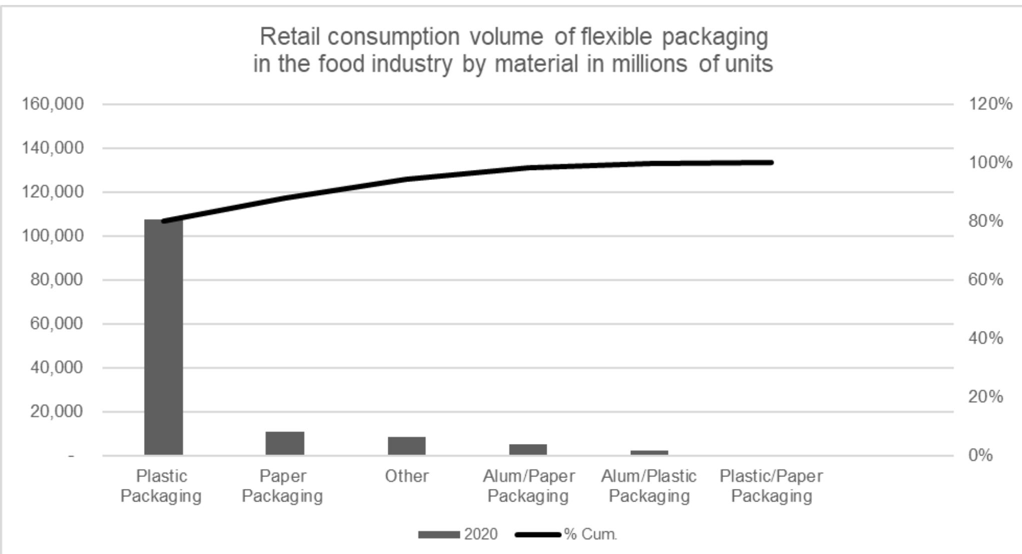

Figure 2: Retail Consumption Volume of Flexible Packaging in the Food Industry by Material in Millions of Units [8]
Source: Euromonitor 2020a

The purpose of this study is to quantitatively identify which food packaging material has a more positive impact on physical, biological, socioeconomic, and environmental aspects, whose use should be promoted in the food industry.

Theoretical Framework

In recent years, numerous articles have been published on the overall environmental impact of plastic packaging, often focusing on a specific aspect of the product life cycle.

The product life cycle is defined as "consecutive and interlinked stages of a product (or service) system, from raw material acquisition or generation from natural resources to final disposal" (International Organization for Standardization 2016, 1). This perspective gives a detailed description of the product life, allowing us to identify significant environmental impacts to mitigate them, thus contributing to sustainable development.

This study carries out an environmental impact assessment of flexible packaging used in the food industry for cookies and snacks based on their life cycle, because this packaging category (flexible paper and plastic) was the most consumed for this food type in 2019, as shown in Figure 3. The analysis is performed for each type of packaging currently used (Euromonitor 2020b).

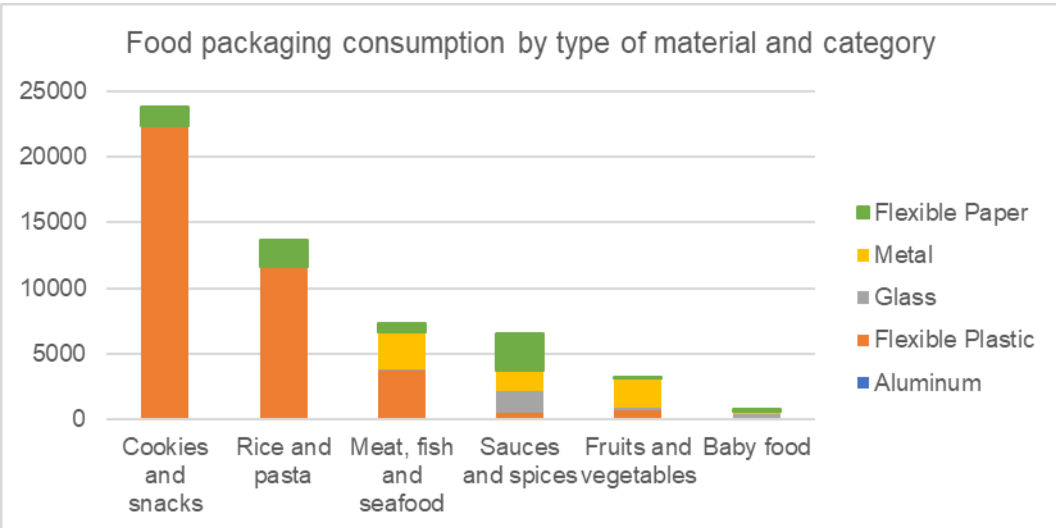

Figure 3: Food Packaging Consumption Volume by Type of Material and Category [8]
Source: Euromonitor 2020b

Flexible food packaging is defined as multilayer packaging made from different materials that must meet certain requirements, such as adequate barrier properties, selective permeability, transportation resistance, and package sealing (Méndez Prieto 2019).

Life Cycle of Plastic Packaging

Flexible plastic packaging in the food industry for cookies and snacks have biaxially oriented polypropylene (BOPP) as its raw material that should be metallized to imbue the material with the barrier properties necessary to protect the food (Calderón Martínez, Meneses Herrera, and Quintanilla Sánchez 2011).

The life cycle of flexible plastic packaging starts with crude oil extraction, raw material of plastic (Plastic Collectors 2020). For this purpose, drill bits or trepanning tools are used to bore oil wells and reach hydrocarbon deposits to then extract the oil with a pumpjack.

Afterward, naphtha is obtained after light distillation, by separating the components based on their volatility (Plastic Collectors 2020). Naphtha then undergoes fluidized-bed catalytic cracking to obtain propylene, which transforms after an addition polymerization process into a larger molecule called propylene (Diquima, n.d.). Finally, after dosing and combining the raw material with water steam and additives, polypropylene is converted into pellets using the pressure pelletizer (pelletizing process), drying the resulting pellets to eliminate water (Baño Martí 2020).

According to Tosar (n.d.) and Packsys Academy (2012), the propylene pellet undergoes an extrusion process to obtain a laminated polypropylene bag. It should be laminated with aluminum-metallized BOPP, which adheres to the polypropylene film by condensation.

The last stage in the life cycle of flexible plastic packaging involves the final treatment. Plastic packages are rarely recycled and end up in landfills, are incinerated or abandoned (Opemed 2020) because plastic recycling is very expensive, requires state-of-the-art technology, and not all waste plastic can be recycled owing to the presence of ink on the packages that prevents its reuse.

Resource renovation proves to be an alternative for the last stage in the life cycle of flexible plastic food packaging. It involves both recycling packages after their final use and contributing to natural life by preventing environmental pollution produced by solid waste. First, plastic is sorted by its characteristics using infrared light based on their Resin Identification Code (RIC). Then, plastic is shredded, decontaminated, dried, melted down, and extruded. Finally, it is combined with other additives to obtain small balls (pellets) that will be used later in new applications (Bolaños Zea 2019).

Impacts of the Life Cycle of Plastic Packaging

Oil extraction is the first stage of the life cycle of plastic packaging and creates a high level of pollution owing to the required water treatments, the release of particulate matter and volatile compounds during the extraction, oil spills in the ocean and soil, noises, and movements (Arnedo and Yunes 2018). Additionally, the sludge that is used in oil drilling prevents the growth and development of sea species and microbial communities by altering their habitats (Bravo 2007). Hydrocarbons severely affect fish tissue too, posing a higher risk of liver disease in humans who consume this type of meat.

In the second stage of production, the catalytic cracking process is first considered. It requires a large investment in technology and components to mitigate the pollutants that cause damage to living tissue (Strubinger, Morales, and Aponte 2014). A harmful emission generated during cracking is carbon monoxide, a highly toxic gas that displaces oxygen in human blood, leading to dizziness or even death (Finklea et al. 1998b). This process also produces the so-called "acid water" that pollutes water and damages aquatic ecosystems. In the second place, the process to produce plastic packaging is considered, which implies consuming large quantities of energy, mostly for the extrusion process, which uses at least 50 percent of the total amount of energy consumed (Vargas-Isaza et al. 2015; Arthuz-López and Pérez-Mora 2019). Additionally, plastic packaging production needs large economic investment, mainly owing to the high energy demand of the required technology, resource depletion, atmospheric emissions, liquid effluent discharge, solid waste generation and other environmental emissions such as carbon dioxide (ZEO 2020; Fernández 2017). Nowadays, the plastic industry is worth over one trillion dollars worldwide, accounting for around 5 percent of the total world trade (United Nations Conference on Trade and Development 2021). In the third place, the plastic industry has demonstrated dynamic growth in terms of employment generation and productivity, having jointly raised employee salaries (Gioza Zuazua and Fernández Massi 2017; CamBioTec 2018). In Mexico, one of the largest plastic producers, around 260,000 new direct jobs, and more than 500,000 new indirect jobs have been created (ICEX España exportación e inversiones 2018). In the fourth place, we consider plastic packaging transportation to factories or stores for their later use. In this part of the process, plastic packaging is usually packed in plastic bags or other polluting materials, implying more plastic consumption (Casanova Rodríguez and Mazo Machado 2020). In addition, the means of transportation used to carry the plastic packages also produce pollutants. Carrying these packages also requires the effort of company personnel, which may often cause ergonomic issues if they do not apply the necessary safety measures (Fernández 2017). Lastly, engine failures can occur during plastic packaging production, which increases temperature and electricity consumption accordingly (Vargas-Isaza et al. 2015). Besides, both reactive and preventive maintenance are really expensive and demand the use of large quantities of resources (Tecnología del plástico 2018).

In the third stage of final treatment, more than 380 million tons of plastic are produced every year, from which a small percentage is recycled, some is burnt, and the rest is disposed of (Buteler 2019). In the case of disposal, plastics have inert characteristics that prevent microorganisms from degrading them, that is, they are nonbiodegradable (Barrera et al. 2013). Therefore, plastic accumulates on the streets, highways, sewers, and landfills. The use of landfills has become an issue, because the nonbiodegradable nature of plastic leads to mass accumulation, which in turn translates into large harmful emissions of gases such as methane (Arandes, Bilbao, and López 2004). Additionally, landfill accumulation means habitat alteration and bird displacement, as well as air pollution attributable to the toxin emissions from combustion and water pollution from plastic disposal in the drainage system (Gómez 2016). Furthermore, plastic has components that may cause disease in humans. Regarding accumulation in oceans and rivers, around 6.4 million tons of plastics are dumped into oceans, forming garbage patches (Socas González 2018). These patches are formed because of the currents and winds, as well as the uncontrolled plastic consumption, mostly from more industrialized countries. The waves, the sun, and the wind disintegrate these plastics into small particles, making their collection impossible, and they end up accumulating into one of the five main garbage patches (Espino Penilla and Koot 2020). Some of the main consequences of these patches are the loss of millions of living creatures, marine flora and fauna endangerment, environmental and water reserve pollution, health issues in the populations, and resource depletion. Both landfill accumulation and solid waste littering damage the landscape, leading to visual pollution in these significant medium category zones (Socas González 2018). Finally, we have plastic waste incineration, which contributes to global warming and leads to the emission of complex hazardous gases that affect health and the environment (Arbaje and Pérez 2020). Waste incineration has proven not to be a solution for plastic elimination, because at least 70 percent of the total mass remains in the form of ashes, being very difficult to control. Moreover, incineration is an expensive process that needs an isolated area in the city and the technology to avoid exceeding the maximum permissible level of emissions.

In addition, plastic also has a socioeconomic impact, because the fishing industry is often affected by contaminated fish or cannot find fish owing to the significant amount of waste particles (Del Cueto Gracia 2016). Plastic waste also affects the tourism industry by damaging the aesthetic value of streets, beaches, and other areas, requiring a large sum of money for daily waste collection. Additionally, plastic loses 95 percent of its value after its first use, and a large quantity ends up in the environment, thus entailing significant economic costs (World Economic Forum 2021).

The last renovation stage is not frequent because of the high cost of the technologies necessary (Ágora Inteligencia Colectiva para la Sostenibilidad 2021). According to this author, the main disadvantage of recycling plastic is resource consumption such as water, cleaning agents, and electricity used to give plastic a new life. Even though recycling plastic pollutes less than producing it, it still emits 1.7 kg of carbon dioxide per kilo of recycled plastic (Z. E. O. 2020). Once the plastic packaging is recycled, it cannot be used to preserve products for human consumption owing to the presence of additives and their low quality (Santos et al. 2005). In addition, the renovation process generates a large amount of emissions and polluting residues, thus requiring strict controls (Sbarbati Nudelman 2020).

Life Cycle of Paper Packaging

Lately, an increasing use of paper packaging, especially Kraft paper, has been reported. Unlike regular paper, Kraft paper has a protection barrier for food. The raw material used for paper production is cellulose, which is obtained through different methods, depending on the selected tree. The first step is to remove the bark and splinter the trunk to obtain the cellulose by chemical or mechanical treatment (Boeykens 2006).

After obtaining the raw material, cellulose is separated from lignin. During the chemical treatment, cellulose is mixed with various chemical agents: caustic soda and sodium sulfide for Kraft paper (López Sardi 2007), to eliminate lignin and form the pulp. Then, the cellulose paste is washed to eliminate residues (Sanz Tejedor, n.d.).

To obtain paper, the virgin or recycled cellulose fibers are mixed with water in a pulper. This mixture is then flattened by the rolls of a paper-making machine. Finally, water is removed from the mixture by different methods. The end product of this process is long sheets of paper rolled up in a roll stock (Comercial Áviles 2019).

Paper packaging is produced using specialized machines that coat the paper roll stock with an inorganic barrier, making them a paper roll stock with a sustainable barrier (Bazar Gráfico 2020). Paper roll stocks are then taken to the graphic industry for printing and die-cutting.

The last stage of the life cycle of flexible paper packaging consists of a final treatment, where residues are incinerated and dumped in the landfill. Incineration involves burning waste material to turn it into ashes. However, this procedure has largely been discontinued in favor of recycling, which brings more environmental benefits (Tangri 2005).

Nonetheless, unlike plastic, paper is easier to reuse, because not so many additives and processes are required for this end. First, paper packages are processed with water, additives, and minerals in a pulper, the product of which is pressed to remove most water. Then, the mixture is centrifuged to eliminate the ink. A second pressing and centrifuge is needed to eliminate impurities. Paper is then bleached using chlorine dioxide, hydrogen peroxide, or sodium hydrosulfite. Finally, this paste runs through a series of rolls to remove the remaining water and form roll stocks of recycled paper (Bazar Gráfico, n.d.).

Impacts of the Life Cycle of Paper Packaging

Raw material extraction is the first stage of paper packaging production. Trees, as the raw material of paper, are often planted as a monoculture, which affects ecosystem diversity and deteriorates the natural landscape. The extension of plantations also has a direct impact on residents, who prefer to abandon the area to look for a different landscape. In addition, to obtain cellulose, entire forests and large amounts of water are consumed, as resources required by forest-based industries, leading to droughts and soil acidification (Torres Fuica 2017). In tropical areas, for instance, deforestation and logging may lead to pest outbreaks because these areas have the optimal conditions for their formation, thus affecting human health. Additionally, areas previously protected by tree shade record increased soil temperature when deforested, thus contributing to climate change (Sociedad Argentina de Pediatría, n.d.). Another aspect to take into consideration is the impact of logging on air quality, as carbon dioxide is released into the atmosphere from the burning of branches and leaves used during cellulose production (López Sardi 2007). The micro ashes formed in the process are borne by air currents into the glaciers, reducing their heat reflection capacity and accelerating melting (Torres Fuica 2017).

The production stage directly impacts air quality owing to the emission of polluting gases such as sulfuric gases that cause acid rain (López Sardi 2007). The high level of air pollution can be harmful to human beings. For instance, respiratory problems attributable to gas emission and bad smells have been reported in residents near paste production plants (Chura Teves and Sanchez Vasquez 2020). However, the implementation of strict quality controls and automation of maintenance operations have proven to reduce these negative impacts on plant workers

(Asociación Nacional de Empresarios de Colombia—ANDI 2017). Furthermore, the cellulose industry consumes a large quantity of water water, which is later discarded with suspended particles, that is, toxic substances that alter the pH value of water and increase temperature (López Sardi 2007). Additionally, pulp production generates wood residues that mostly end up in water bodies, increasing the accumulation of organic matter and altering the habitat of aquatic species. Regarding the atmospheric emissions, this process produces greenhouse gases such as carbon dioxide, which contributes to global warming (Torres Fuica 2017). However, production plants of cellulose paste have attempted to implement methods to counteract the impacts on the air, water, and soil (Finklea et al. 1998a). To alleviate the impact on water, wastewater cleaning filters have been installed to reduce the quantity of organic matter that ends in water sources. Besides, new technologies manage to reduce combustion gases, and the implementation of gas scrubbers helps preserve the environment. Lastly, regarding solid waste generation, the ashes from this process are given a second use, for instance, in highway construction (Finklea et al. 1998a).

Both the paper industries that produce cellulose and the paper-making industries have a positive socioeconomic impact. The paper industry is currently growing, generating employment, contributing to the internal development by buying local raw materials, and promoting recycling, which in turn translates into a positive environmental impact (Asociación Nacional de Empresarios de Colombia—ANDI 2017). Furthermore, cellulose production as well as paper production invest in innovation in an attempt to mitigate their environmental impacts by implementing new technologies. In 2020, investment in the paper industry totaled 1,720 million Euros and exports reached 4,618 million Euros (Asociación Española de Fabricantes de Pasta Papel y Cartón 2018). However, nowadays, the paper industry accounts for 4 percent of the world energy consumption, because it takes on average 0.75 tons of oil to produce a ton of paper (Doldán García and Chas Amil 2001). The main impacts of packaging production in the graphical industry come from ink and solvent residues used to clean the machines, which evaporate into the environment (Fundación entorno Empresa y Medio ambiente 1998). In general, let us not forget that the paper industry needs transportation to connect the different stage of its life cycle, which generates a significant part of the overall greenhouse gas emissions it produces. Gas generation produced during transportation reaches a total of 150 kg of carbon dioxide, including, for instance, the air transportation from Europe to Latin America (Hortal et al. 2018).

The third stage of the life cycle of paper packaging is the final treatment, which includes littering, incineration, and landfill disposal. Solid waste incineration exerts the most severe environmental impact owing to greenhouse gas emissions: every ton of waste emits one ton of carbon dioxide (New ISO 14001:2015 2019). Furthermore, littering and dumping in landfills increase the emission of high concentrations of methane, thus contributing to the greenhouse effect, as anaerobic decomposition of waste occurs that alters the flora and fauna habitat. In addition, landfills are sources of infection that can cause very serious diseases, affecting people’s health and the environment (Reciclajes Avi 2015). Finally, one bond paper sheet takes approximately one year to decompose, increasing soil pollution produced by solid waste and affecting the landscape with the accumulated waste (Organismo de Evaluación y Fiscalización Ambiental [OEFA] 2013).

Resource renovation proves to be an alternative for the third stage in the life cycle of paper packaging. Firstly, deforestation is reduced as raw materials are reused, and the impact of logging is also minimized. In addition, it requires less water for tree planting and paste production, meaning a lower impact on the environment (Sociedad Argentina de Pediatría, n.d.). However, although cellulose produced for Kraft paper does not require a bleaching method, paste must be bleached with chlorine to be reused in the paper industry (Boeykens 2006). Over the years, new bleaching techniques have been implemented, but the use of chlorine is still very common. Organochlorides are highly polluting agents, which have been found in different places such as water, living organisms, and so on (Greenpeace México, n.d.). This substance is found mainly in marine life, as it is part of the effluents from the boiling process. This is where sea animals consume organochlorides, which in turn affect humans through consumption of contaminated species, posing a greater health risk.

Summary of the Impacts of the Life Cycle of Plastic Packaging

The summary of impacts of the life cycle of plastic packaging is provided below, including references to the bibliography from the theoretical framework (Table 1).

Table 1: Summary of the Impacts of the Life Cycle of Plastic Packaging

Process	*Element*	*Impact*	*Author*
Extraction	*Physical*	Release of particulate matter and volatile compounds. Spills in the ocean and soil.	Arnedo and Yunes (2018), Bravo (2007).
	Biological	Marine habitat alteration.	
	Socioeconomic	Health risk of liver diseases, noise, and vibrations.	
Production	*Physical*	Acid water generation, which causes damage to aquatic ecosystems and pollutes water. Consumption of large amounts of energy, resource depletion. Generation of atmospheric emissions, discharge of liquid effluents, generation of solid waste, heavy metals, toxic compounds. Consumption of more plastic, resource depletion. Noise pollution.	Strubinger, Morales, and Aponte (2014), Finklea et al. (1998b), Vargas-Isaza et al. (2015), Arthuz-López and Pérez-Mora (2019), Fernández (2017), Casanova Rodríguez and Mazo Machado (2020), Fernández (2017), Ágora Inteligencia Colectiva para la Sostenibilidad (2021), Tecnología del Plástico [Technology of Plastic] (2018).
	Biological	Alteration of aquatic ecosystems.	
	Socioeconomic	Skin deterioration produced by UV radiation. Health and safety risks for personnel. Modern technology is required, high investment costs. Ergonomic issues during the transportation of goods. Employment generation.	

Final Treatment	*Physical*	Accumulation of plastic waste in the streets, roads, sewers, soil pollution. Air pollution from the emissions of toxins and hazardous gases such as methane. Water pollution from waste disposal in the sewers, formation of garbage patches. Air pollution. Contribution to global warming.	Barrera et al. (2013), Arandes, Bilbao, and López (2004), Gómez (2016), Socas González (2018), Arbaje and Pérez (2020), Del Cueto Gracia (2016), World Economic Forum (2021), Micaela Buteler (2019), Espino Penilla and Koot (2020).
	Biological	Alteration of the fauna habitat and bird displacement. Marine flora and fauna extinction.	
	Socioeconomic	Deterioration of human health. Significant economic costs. Negative impact on the fishing industry due to the alteration of marine fauna. Negative impact on the tourism industry due to polluted beaches and landscapes.	
Resource Renovation	*Physical*	Depletion of resources such as water and electricity. Emission of gases and polluting waste.	Vargas-Isaza et al. (2015), Zero Emissions Objective (2020), Santos et al. (2005), Sbarbati Nudelman (2020).
	Socioeconomic	High costs for separating and sorting plastics, technologies, treatments, etc.	

Source: Bittrich, Ruiz, and Larios 2021

A schematic graphical representation of the summary table can be seen in Figure 4.

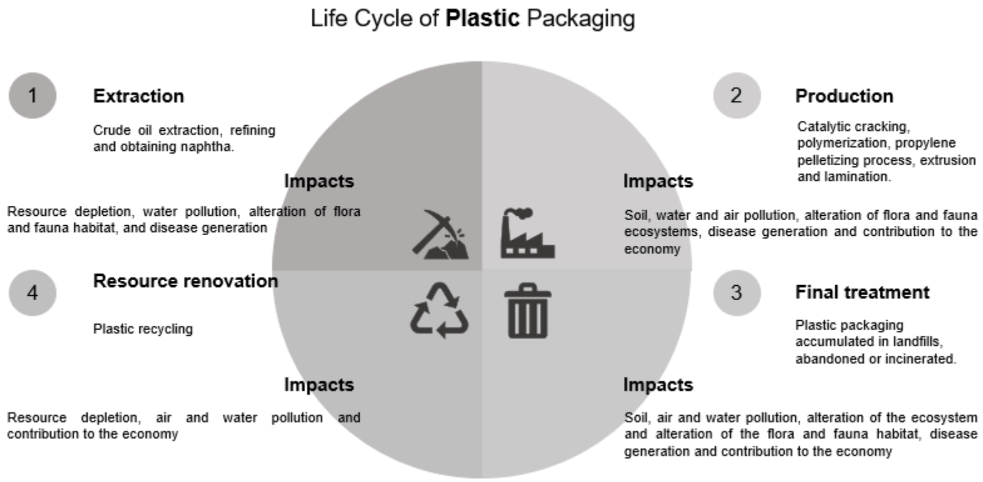

Figure 4: Schematic Representation of the Life Cycle of Plastic Packaging
Source: Bittrich, Ruiz, and Larios 2021

Summary of the Impacts of the Life Cycle of Paper Packaging

In the case of paper, the information from the life cycle corresponding to the information explained in the theoretical framework is compiled in Table 2.

Table 2: Summary of the Impacts of the Life Cycle of Paper Packaging

<table>
<tr><th>Process</th><th>Element</th><th>Impact</th><th>Author</th></tr>
<tr><td rowspan="3">Extraction</td><td>Physical</td><td>Damage to the landscape owing to monoculture plantation.
Acidification and droughts produced by the consumption of entire forests.
Increase in soil temperature.
Air pollution produced by the generation of ashes.</td><td rowspan="3">Torres Fuica (2017), López Sardi (2007), Sociedad Argentina de Pediatría [Argentina Society of Pediatrics] (n.d.).</td></tr>
<tr><td>Biological</td><td>Alteration of the ecosystem due to monoculture plantation.
Alteration of the flora and fauna habitat.</td></tr>
<tr><td>Socioeconomic</td><td>Abandoned homes due to landscape alteration.
Health deterioration due to the build-up of pests in deforested areas.</td></tr>
</table>

Production	*Physical*	Air pollution and acid rain due to the emission of sulfuric gases. Contribution to the greenhouse effect due to carbon dioxide emissions. Deterioration of soil and water flows. Water pollution and pH variation produced by airborne particles and organic matter. Soil pollution produced by solid waste generation.	Torres Fuica (2017), López Sardi (2007), Chura Teves and Sanchez Vasquez (2020), Asociación Nacional de Empresarios de Colombia—ANDI [Colombian Association of Entrepreneurs] (2017), Finklea et al. (1998a), Doldán García and Chas Amil (2001), Asociación Española de Fabricantes de Pasta, Papel y Cartón (2018).
	Biological	Plant deterioration produced by the emission of sulfuric gases.	
	Socioeconomic	Deterioration of human health due to the emission of sulfuric gases. Respiratory problems in people who live near paper industries. Health and safety risks due to the exposure to heat and chemical products. Economic growth due to employment generation and investment in innovation.	
Final Treatment	*Physical*	Air pollution due to the emission of greenhouse gases.	OEFA [Agency for Environmental Assessment and Enforcement] (2013), Escuela Europea de Excelencia (2019), Tangri (2005).
	Biological	Alteration of the flora and fauna habitat.	
Resource Renovation	*Physical*	Reduction of the impact of deforestation. Reduction of water consumption and contribution to droughts. Reduction of gas pollution that contributes to the greenhouse effect. Reduction of energy consumption to produce paper.	López Sardi (2007), Chura Teves and Sanchez Vasquez (2020), Greenpeace México (n.d.).
	Biological	Habitat alteration due to the use of chlorine to bleach recycled paper. Changes in seafood consumption due to the presence of organochlorides.	
	Socioeconomic	Risk to human health due to the consumption of organochlorides in marine species.	

Source: Bittrich, Ruiz, and Larios 2021

Just as for plastic packaging, a summary graph of the life cycle of paper packaging is presented (see Figure 5).

Figure 5: Schematic Representation of the Life Cycle of Paper Packaging
Source: Bittrich, Ruiz, and Larios 2021

Materials and Methods

In order to assess the environmental impacts from each stage of the life cycle per type of material, plastic and paper, the Leopold Matrix was applied to measure in quantitative terms the impact of each material on different environmental factors. The literature review of scientific and supplementary articles published in recent years was used as a basis for completing the matrix, considering a sample of sixty four references with key information.

In the cause–effect matrix, the environmental element is recorded in the rows and the action in the columns so that they relate to show an environmental effect or impact. If an interaction occurs, each box is divided by a diagonal line. The magnitude is recorded in the upper part with numbers ranging from 1 to 10, with a (+) sign if it is beneficial or a (–) sign if it is an adverse effect. The importance is rated from 1 to 10, always with a positive sign (Garmendia et al. 2005). Finally, the total number of interactions will be calculated taking into account the arithmetic average to obtain the final value of the impact per type of packaging. The environmental elements consider three types of scope:

1. *Physical Scope*: It refers to the external conditions that surround us, considering main aspects such as soil, air, water, and landscape.
2. *Biological Scope*: It focuses on flora and fauna, that is, animals, microorganisms and plants, flowers and trees.
3. *Socioeconomic Scope*: It considers the economic and social capacities through the analysis of aspects such as employment, health, population, and economy.

The environmental actions correspond to each life cycle stage and are differentiated by type of material. The following actions were assessed for plastic:

1. *Extraction*: It considers the actions to obtain raw materials such as blasting and drilling, well drilling, and offshore structure.
2. *Production*: It considers activities such as resin refining/production, packaging production, packaging transportation, and failure control.

3. *Final Treatment*: It identifies the impact of landfills, incineration, or littering of plastic packaging.
4. *Resource Renovation*: It explicitly considers recycling, including the management and control of natural life and waste recycling.

In the case of paper, the actions to be analyzed are presented as follows:

1. *Extraction*: It assesses the activities to obtain wood such as forest use, plantations, and soil alteration.
2. *Production*: It refers to obtaining paper and cellulose, as well as packaging production, transportation, and failure control.
3. *Final Treatment*: It identifies the impact of landfills, incineration, or littering of paper waste.
4. *Resource Renovation*: It considers recycling, reforestation, and management and control of natural life.

Based on these environmental elements and actions, a rating scale of the magnitude and importance of impacts is developed to prepare the Leopold Matrix, taking into consideration the categories used by the Agency for Environmental Assessment and Enforcement (Organización de Evaluación y Fiscalización Ambiental [OEFA] 2013). The following magnitude rating scale table was prepared (Table 3).

Table 3: Magnitude Rating

Magnitude Rating	*Probability of Occurrence*	*People Exposed*	*Extension*
1	Unlikely	< 5	Specific
3	Possible	5–29	Local
5	Likely	30–59	District
7	Highly likely	60–100	Regional
10	Extremely likely	> 100	National

Source: OEFA 2013

The lower limit considers an unlikely situation with less than 5 people exposed to this impact and an extension that affects only one specific area of the project. The maximum limit refers to a more critical situation where the impact is extremely likely to occur and expose more than 100 people with a nationwide extension. Table 4was developed to show the importance rating.

Table 4: Importance Rating [66]

Importance Rating	*Hazardousness*	*Sensitivity*
1	Nonhazardous	Null
3	Slightly hazardous	Low
5	Moderately hazardous	Medium
7	Hazardous	High
10	Very hazardous	Extreme

Source: OEFA 2013

The lower limit refers to a situation of slight and reversible damage of low magnitude, whose impact will not cause a significant effect on the environment, that is, the sensitivity is null. The maximum limit establishes a very hazardous critical situation of great magnitude, which extremely affects the surroundings and the environment, with consequences in the medium and long term.

Results

Taking into account the aforementioned elements and actions for each type of material, the Leopold impact assessment matrices were prepared for the life cycles of plastic packaging and paper packaging (Figure 6).

Stages of the life cycle			Extraction			Production				Final Treatment			Resource Renovation						
Environmental actions / Environmental elements			Blasting and Drilling	Well Drilling	Offshore structures	Resin production / Refining	Packaging production	Transportation	Failure control	Landfill Abandonment	Incineration	Waste Disposal	Natural life management and control	Waste recycling	Positive averages	Negative averages	Impact of subcomponents	Impact of component	Impact of the project
Environmental factors		Environmental impacts	Results																
Physical	Soil	Soil pollution	-6/4	-6/5						-8/6		-7/8				4	-158	-462	-704
		Resource depletion					-4/3							-3/5		2	-27		
	Atmosphere	Contribution to climate change				-3/2		-3/2		-4/3	-6/5	-6/5				5	-84		
		Air pollution					-4/3	-3/2	4/3		-7/6	-6/6		3/5	2	4	-69		
	Water	Water pollution with toxic matter	-4/3	-5/4		-3/2	-5/4									4	-58		
		Water resource depletion												-5/3		1	-15		
	Landscape	Landscape deterioration			-1/1					-5/-5		-5/-5				3	-51		
Biological	Flora	Ecosystem alteration			-2/2					-6/4		-7/5				3	-63	-299	
		Habitat alteration	-3/3							-6/4	-4/3	-7/5	5/6		1	4	-50		
	Fauna	Ecosystem alteration			-2/2					-8/5		-9/6				3	-98		
		Habitat alteration	-3/3							-8/5	-5/3	-9/6	5/6		1	4	-88		
Socioeconomic	Employment	Employment generation					4/6								1		24	57	
	Health	Disease generation	-3/2	-3/2		-3/5		-3/4			-3/5	-3/4				6	-66		
	Population	Migration of residents										-3/2				1	-6		
	Economy	Contribution to the economy				5/3	5/3		7/3		3/3		5/4	5/5	6		105		
Positive averages						1	2		2		1		3	2					
Negative averages			5	3	3	3	3	3		7	5	10		2					
Arithmetic average			-60	-56	-9	-12	-5	-24	33	-213	-105	-343	80	10			-704		

Figure 6: Leopold Matrix for the Life Cycle of Plastic Packaging
Source: Bittrich, Ruiz, and Larios 2021

As can be seen, the Leopold matrix for plastic has an overall result of –704 and a total of 55 interactions between the aforementioned elements and actions. The element that stands out most is the physical one, with a score of –462, mostly owing to the soil and air pollution caused mainly by packaging production, landfill accumulation, incineration, and formation of garbage patches. This element does not have any positive interaction that can counteract its harmful impacts on the environment, as its only 2 positive interactions (failure control and waste recycling) have a low magnitude and impact.

The next element with the highest score is the biological factor, with –299, having waste accumulation and incineration and the formation of plastic garbage patches during final treatment as its most negative impacts on flora and fauna. It should be noted that the life cycle of plastic packaging poses a greater impact on the fauna, especially on marine life during final treatment. This element only shows positive impacts for the action of natural life management and control; however, the score is not high enough to outweigh the negative impacts.

Finally, we have the socioeconomic element, with a score of 57, being the most positive interaction owing to its contribution to the economy and employment generation in the production and resource renovation stages. This element is the only one that has a positive value, despite the negative interactions attributable to disease generation risk and migration of residents (Figure 7).

Stages of the life cycle			Extraction			Production				Final Treatment			Resource Renovation						
Environmental Elements / Environmental Actions			Forest exploitation	Plantations	Soil alterations	Obtaining cellulose and paper	Packaging production	Transportation	Failure control	Landfill Abandonment	Incineration	Waste Disposal	Waste recycling and reforestation	Natural life management and control	Positive averages	Negative averages	Impact of subcomponents	Impact of the component	Impact of the project
Environmental factors		Environmental impacts	Results																
Physical	Soil	Soil alteration	-5/6										4/5		1	1	-10	-397	-600
		Soil pollution			-4/3					-5/2			3/2		1	2	-16		
	Atmosphere	Contribution to climate change	-3/3			-7/7		-5/6	3/2	-7/3	-6/4	-2/3		6/5	2	6	-103		
		Air pollution	-6/3			-7/7	-1/2	-5/4		-7/2	-6/4					6	-127		
	Water	Water pollution with toxic matter				-7/7			3/2					6/4	2	1	-19		
		Water pollution with solid waste				-7/7			3/2						1	1	-43		
	Landscape	Landscape deterioration	-7/7	-7/4						-5/2		-3/4	4/5		1	4	-79		
Biological	Flora	Ecosystem alteration			-8/8				3/2	-2/3	-3/5			4/6	2	3	-55	-184	
		Habitat alteration				-6/5						-2/2	-6/5			3	-64		
	Fauna	Ecosystem alteration			-4/4				3/2	-2/3	-3/5			3/4	2	3	-19		
		Habitat alteration				-6/5						-2/2	-4/3			3	-46		
Socioeconomic	Employment	Employment generation				5/3									1		15	-19	
	Health	Disease generation	-3/5		-3/8	-4/5	-1/1		3/4				-8/8		1	5	-112		
	Population	Migration of residents		-3/2												1	-6		
	Economy	Contribution to the economy				8/9							2/6		2		84		
Positive averages						2			6				4	4					
Negative averages			5	2	4	7	2	2		6	4	4	3						
Arithmetic average			-121	-34	-116	-189	-3	-50	42	-67	-78	-26	-48	90	-600				

Figure 7: Leopold Matrix for the Life Cycle of Paper Packaging
Source: Bittrich, Ruiz, and Larios 2021

After the impact analysis and assessment of the life cycle of paper packaging, the matrix resulted in a value of –600, with a total of 55 interactions between elements and actions. The most relevant environmental factor is the physical element, with a value of –397, mainly attributable to air pollution and the contribution to climate change during the production and final treatment stages. Additionally, a high level of water pollution produced by organic matter and suspended solids is identified for the production stage; however, this case shows that actions such as failure control and management and control of natural life manage to alleviate the negative impacts of packaging life cycle.

The next element with the highest number of negative impacts is the biological factor, with a score of –184. Actions during the extraction and final treatment stages are the ones that have a negative impact on the flora and fauna. Soil alterations are identified as the most significant impact under this factor, owing to the changes it causes in the ecosystem of the flora. The only positive interactions are found in failure control and natural life management and control, but they do not significantly contribute to improving the score.

Finally, the socioeconomic element was assessed with a score of –19. The life cycle of paper packaging positively contributes to the economy and employment generation during the production and resource renovation stages. However, this element is outweighed by the risk of disease generation during raw material extraction, cellulose production, and paper recycling.

In order to analyze the results from both matrices jointly, the following comparative table has been prepared considering the selected environmental factors and the interactions generated during the packaging life cycle (Table 5).

Table 5: Comparative Table of the Life Cycles of Plastic and Paper Packaging

Factor		*Plastic*	*Paper*
Physical	*Soil*	Plastic poses a greater negative impact with –185 points due to soil contamination, especially during raw material extraction and final treatment where waste is disposed of or littered.	Paper poses a negative impact of –26 points on the soil during extraction; however, this impact is mitigated with reforestation.
	Atmosphere	Plastic final treatment contributes to climate change with a score of –153 due to greenhouse gas emissions.	Paper creates more air pollution with a score of –230 during cellulose and paper production, where sulfuric gases are emitted.
Physical	*Water*	In this case, both plastic (–73) and paper (–62) generate water pollution during the production stage due to the generation of toxic effluents that end up in water sources.	
	Landscape	Plastic does not pose greater impact during the extraction because offshore structures are usually located in isolated areas; however, landscape deterioration occurs during the final treatment and, therefore, it has a score of –51.	Paper has a lower negative impact on the landscape, with –79 points, due to tree plantations as industrial monocultures.
Biological	*Flora*	In this case, both plastic and paper negatively impact the flora. Paper has a score of –119 due to soil alterations and waste accumulation. On the other hand, plastic has a score of –113 due to the pollution and impact during the final treatment caused by packaging littering, incineration, and disposal.	
	Fauna	Plastic poses the greatest negative impact on the fauna, with –186 points, due to waste accumulation and generation of plastic garbage patches.	Paper has a less negative impact, with –65 points; however, the negative score is due to the generation of effluents with organochlorines that affect marine life.
Socio-Economic	*Employment*	Both the plastics industry (24) and the paper industry (15) have a positive impact on employment generation as packaging is a high-consumption product, necessary for food protection.	
	Health	Plastic production and disposal generate polluting gases that have an impact on health; therefore, the impact is given a score of –66.	Paper poses a higher health risk, with a score of –112, especially during extraction and production, because potential pests are created and sulfur gases that cause respiratory problems are emitted.
Socio-Economic	*Population*	Both the plastic industry (–6) and the paper industry (–6) cause migration of residents, in the case of plastic due to waste accumulation and in the case of paper due to the deterioration of the landscape caused by plantations.	
	Economy	Both industries contribute to the economy as a result of the investments made; however, plastic has a greater influence on this aspect as it is a massive industry; therefore, it has a score of 105, while paper has a score of 84.	

Source: Bittrich, Ruiz, and Larios 2021

As can be seen under the physical element, plastic proves to be more harmful than paper, because the latter manages to alleviate the negative impacts thanks to resource renovation. Concerning the biological aspect, plastic is more harmful owing to the generation of effluents and the formation of plastic garbage patches that affect marine flora and fauna. However, paper is also considered harmful because of the organochlorines produced by using chlorine during cellulose bleaching. Finally, under the socioeconomic element, both materials are considered to cause diseases, but the negative effects of plastic are outweighed by the positive impacts obtained with employment generation and contribution to the economy.

Discussion

After the quantitative assessment of the life cycle of flexible plastic and paper food packaging using the Leopold Matrix, it can be concluded that both materials are polluting and harmful to the environment; however, paper is more likely to be reused, mitigating the impacts generated.

The results obtained show that none of the two materials under evaluation should be encouraged in the food industry, because they do not cause positive impacts on the physical, biological, and socioeconomic aspects in general.

Recent research confirms the impact caused by microplastics, particularly the deterioration of the natural habitat and pollution caused by littering and waste accumulation. Despite the awareness of the problem of plastic pollution, its indiscriminate use, improper packaging recycling, and landfill accumulation still continue, causing further damage to the environment (Kumar et al. 2021). It is also confirmed that the percentage of recycled plastic is close to 50 percent owing to the limitations of some polluting components (Otto et al. 2020).

Furthermore, the analysis of plastic and paper packaging confirms that both materials are potentially harmful to the environment, owing to the mass flow and energy consumed during their life cycle; however, these authors emphasize that further research is required to obtain more accurate results and data (Zabaniotou and Kassidi 2003).

Additionally, an increased use of paper in food packaging is confirmed, but its protective barrier is limited; therefore, it is often combined with other materials, reducing the possibility to recycle it (Kumar et al. 2021). However, the adverse impact of paper on the health and the environment should not be disregarded. It is therefore suggested to develop better recycling policies and waste disposal techniques (Deshwal, Panjagari, and Alam 2019).

Taking into account the opinions of these articles and the results obtained, the use of other materials with less environmental impact is proposed. A study on the use of nanofibrillated cellulose as a raw material for packaging has been conducted in recent years. The main function of nanofibrillated cellulose is to be a barrier agent to protect food from external pollutants (Jin et al. 2021). This cellulose is a bio-based nanomaterial, that is, it is obtained from natural resources such as wood, plants, bacteria, and algae (Kim et al. 2015; Lopattananon et al. 2006).

Several authors present the extraction of nanofibrillated cellulose from natural waste such as pineapple peel, leaves of mango trees, and crop straw, which usually end up discarded owing to their little use (Lopattananon et al. 2006; Cejudo Bastante et al. 2021). Additionally, this waste is often burnt, exerting a negative impact on the environment (Miao, Lin, and Bian 2020).

For this reason, we suggest the possibility of extracting nanofibrillated cellulose from this waste to give them new applications for packaging production in the pharmaceutical, chemical, and paper industries owing to its “high thermal stability, high mechanical strength and water retention capacity” (Martín 2019). This material could reduce impacts, as it is sourced from the reuse of waste and is fully compostable, biodegradable, and biocompatible (Martín 2019).

REFERENCES

Ágora Inteligencia Colectiva para la Sostenibilidad. 2021. "El coste social del plástico: el uso de productos plásticos cuesta al mundo 3,7 billones de dólares" [The Social Cost of Plastic: The Use of Plastic Products Costs the World $3.7 Trillion]. https://www.agorarsc.org/el-coste-social-del-plastico-el-uso-de-productos-plasticos-cuesta-al-mundo-37-billones-de-dolares/.

Arandes, José, Javier Bilbao, and Danilo López. 2004. "Reciclado de Residuos Plásticos" [Recycling Plastic Residues]. *Revista Iberoamericana de Polímeros* 5 (1): 28–45. https://dialnet.unirioja.es/servlet/articulo?codigo=1048871&orden=0&info=link

Arbaje, Isabela, and Franchesca Pérez. 2020. "Utilización de Opciones Ecoamigables En Las Clínicas Odontológicas Para La Reducción Del Impacto Ambiental de Los Materiales Desechables" [Alternatives in Dental Clinics to Reduce the Environmental Impact of Disposable Materials]. Bachelor's Degree thesis, Universidad Iberoamericana. https://repositorio.unibe.edu.do/jspui/bitstream/123456789/265/1/170046_TF.pdf.

Arnedo, Ana, and Karla Yunes. 2018. "Fracking: Extraction Unconventional Gas and Oil, and Environmental Impact." Bachelor's Degree thesis, Universidad de San Buenaventura. https://agua.org.mx/wp-content/uploads/2018/02/Fracking-Extracci%C3%B3n-gas_Arnedo_2015.pdf.

Arthuz-López, Lizette, and Walter Pérez-Mora. 2019. "Alternativas De Bajo Impacto Ambiental Para El Reciclaje Del Poliestireno Expandido a Nivel Mundial" [Low Environmental Impact Alternatives for Recycling Expanded Polystyrene at Global Level]. *Informador Técnico* 83 (2): 209–219. https://doi.org/10.23850/22565035.1638.

Asociación Española de Fabricantes de Pasta Papel y Cartón. 2018. "Agenda Sectorial Industria Papelera" [Paper Industry Sector Agenda]. https://industria.gob.es/es-es/Servicios/AgendasSectoriales/Agenda%20sectorial%20de%20la%20industria%20papelera/agenda-sectorial-Industria-papelera.pdf.

Asociación Nacional de Empresarios de Colombia—ANDI. 2017. "Informe de Sostenibilidad 2017" [Sustainability Report 2017]. http://www.andi.com.co/Uploads/INFORME%20PULPA%20PAPEL%20Y%20CARTO%CC%81N%20VERSIO%CC%81N%202019.pdf.

Baño Martí, Eduardo. 2020. "Producción de Pellets ¿Cómo Realizarlo Correctamente y Detectar Defectuosidades?" [Pellet Production. How to Perform Pellet Production Correctly and Detect Defects?]. *Interempresas*. https://www.interempresas.net/Plastico/Articulos/266861-Produccion-de-pellets-Como-realizarlo-correctamente-y-detectar-defectuosidades.html.

Barrera, Dorelys, María Márquez, José Yegres, and Patricia Navas. 2013. "Producción de Plástico Parcialmente Degradable Con Polietileno de Alta Densidad (PEAD) y La Dextrina Del Desecho de Solanum Tuberosum" [Production of Partially Degradable Plastic with High-Density Polyethylene (PEAD) and Dextrine from Solanum Tuberosum Waste]. *QuímicaViva* 12 (1): 27–38. https://www.redalyc.org/pdf/863/86326331004.pdf.

Bazar Gráfico. 2020. "Para La Producción de Papel Barrera Sostenible" [For the Production of Sustainable Barrier Paper]. https://bazargrafico.com/para-la-produccion-de-papel-barrera-sostenible/.

Boeykens, Susana. 2006. "Procesos Para La Producción de Papel y Pulpa" [Process for Paper and Pulp Production]. *Encrucijadas* 38: 1–4. http://repositoriouba.sisbi.uba.ar/gsdl/collect/encruci/index/assoc/HWA_416.dir/416.PDF.

Bolaños Zea, Juan Jose. 2019. "Reciclado de Plástico PET" [Recycling PET Plastic]. Bachelor's Degree thesis, Universidad Católica San Pablo. http://repositorio.ucsp.edu.pe/bitstream/UCSP/16146/1/BOLA%C3%91OS_ZEA_JUA_PET.pdf.

Bravo, Elizabeth. 2007. “Los Impactos de La Explotación Petrolera En Ecosistemas Tropicales y La Biodiversidad” [The Impacts of Oil Exploitation on Tropical Ecosystems and Biodiversity]. *Acción Ecológica* 1: 4–61. https://www.inredh.org/archivos/documentos_ambiental/impactos_explotacion_petrolera_esp.pdf.

Buteler, Micaela. 2019. “El Problema Del Plástico ¿Qué Es La Contaminación Por Plástico y Por Qué Nos Afecta a Todos?” [What Is Plastic Pollution and Why Does It Affect Everyone?]. *Desde La Patagonia Difundiendo Saberes* 16 (28): 1–5. http://desdelapatagonia.uncoma.edu.ar/wp-content/uploads/2019/12/13.-Buteler_Revista-28.pdf.

Calderón Martínez, Marcia Noemí, Andrea Stephanie Meneses Herrera, and Allan Emanuel Quintanilla Sánchez. 2011. “Evaluación Técnica de Alternativas Para El Reciclaje y Reutilización de Los Empaques Laminados de Polipropileno y Polipropileno Metalizado” [Technical Evaluation of Alternatives for Recycling and Resuing Polypropylene and Metallized Polypropylene Laminated Packaging]. Bachelor’s Degree thesis, Universidad de El Salvador. https://repositorioslatinoamericanos.uchile.cl/handle/2250/158684.

CamBioTec. 2018. “Análisis de Competitividad Del Sector Plástico En El Estado de México” [Competitiveness Analysis of the Plastics Sector in the State of Mexico]. https://docplayer.es/138332021-Analisis-de-competitividad-del-sector-plasticos-en-el-estado-de-mexico-analisis-de-competitividad-del-sector-plastico-estado-de-mexico-en-el.html.

Casanova Rodríguez, John Alejandro, and Joan Andrés Mazo Machado. 2020. “Diseño de Una Propuesta Para Reducir La Contaminación Producida Por El Uso de Productos Usar—Tirar En El Transporte de Almuerzos de Ejecutivos En La Ciudad de Cali” [Design of a Proposal to Reduce Pollution Caused by the Use of Throw-Away Products in the Transportation of Executive Lunches in the City of Cali]. Bachelor’s Degree thesis, Universidad Autónoma de Occidente. http://red.uao.edu.co//handle/10614/12762.

Cejudo Bastante, Cristina, Nuno H. C. S. Silva, Lourdes Casas Cardoso, Casimiro Mantell Serrano, Enrique J. Martínez de la Ossa, Carmen S. R. Freire, and Carla Vilela. 2021. “Biobased Films of Nanocellulose and Mango Leaf Extract for Active Food Packaging: Supercritical Impregnation versus Solvent Casting.” *Food Hydrocolloids* 117: 1–2. https://doi.org/10.1016/j.foodhyd.2021.106709.

Cenergia. 2020. “Bolsas Plásticas Biodegradables En Perú” [What Are Biodegradable Bags and How Long Do They Take to Degrade?]. https://cenergia.org.pe/blog/bolsas-plasticas-biodegradables-peru/.

Chura Teves, Heiddy Yesenia, and Reydi Sanchez Vasquez. 2020. “El Impacto Ambiental Del Ciclo de Vida Del Papel En El Perú” [The Environmental Impact of Paper Life Cycle in Peru]. Bachelor’s Degree thesis, Universidad Peruana Unión. https://repositorio.upeu.edu.pe/handle/20.500.12840/4113.

Comercial Áviles. 2019. “¿Cuál Es El Proceso de Reciclaje Del Papel?” [What Is the Paper Recycling Process?]. https://www.comercialaviles.com/blog/proceso-de-reciclaje-del-papel/.

Del Cueto Gracia, José Del. 2016. “La Nueva Economía Del Plástico” [The New Plastic Economy]. Plastics Technology. https://www.pt-mexico.com/articulos/la-nueva-economia-del-plastico.

Deshwal, Gaurav, Narender Raju Panjagari, and Tanweer Alam. 2019. “An Overview of Paper and Paper Based Food Packaging Materials: Health Safety and Environmental Concerns.” *Journal of Food Science and Technology* 56 (10): 4391–4403. https://pubmed.ncbi.nlm.nih.gov/31686671/.

Diquima. n.d. “Etileno y Derivados” [Ethylene and Derivates]. Accessed May 25, 2021. http://www.diquima.upm.es/old_diquima/docencia/tqindustrial/docs/etileno_08.pdf.

Doldán García, X. R., and Ma. L. Chas Amil. 2001. "La Contaminación de La Industria de Pasta-Papel En Galicia: Un Análisis de Flujos de Materiales y Energía" [Pollution in the Paste-Paper Industry in Galicia: A Material and Energy Flow Analysis]. *Estudios de Economía Aplicada* 18: 143–158. https://www.redalyc.org/pdf/301/30118206.pdf.

Espino Penilla, Marisol, and Yenthl Koot. 2020. "Nuestro Mundo Cubierto de Plástico: De La Movilidad Global Del Plástico a Las Consecuencias y Respuestas Locales" [Our World Covered by Plastic: From Global Plastic Transportation to Local Consequences and Responses]. *Informes Científicos Técnicos—UNPA* 12 (4): 146–160. https://publicaciones.unpa.edu.ar/index.php/ICTUNPA/article/view/759/793.

Euromonitor. 2020a. *Retail Consumption Volume of Flexible Packaging in the Food Industry by Material in Millions of Units*. London: Euromonitor International.

Euromonitor. 2020b. *Food Packaging Consumption Volume by Type of Material and Category*. London: Euromonitor International.

Fernández, Blanca. 2017. "Evaluación Del Impacto Ambiental de Los Sistemas de Recogida y Transporte de Residuos Urbanos: Sistema Convencional Frente a Neumático" [Environmental Impact Assessment of Urban Waste Collection and Transportation Systems: Conventional System vs. Pneumatic System]. Bachelor's Degree thesis, Universidad Politécnica de Madrid. https://oa.upm.es/47675/1/TFG_BLANCA_FERNANDEZ_CARRASCO.pdf.

Finklea, Jhon, Georges Coppée, Vilma Hunt, Richard Kraus, Wolfgang Lauring, Jacqueline Messite, Steven Sauter et al. 1998a. "Industria del papel y de la pasta de papel" [Paper and Paper Paste Industries]. In *In the Encyclopedia of Occupational Health and Safety*, edited by Kay Teschke and Paul Demers, 72. Ginebra: Oficina Internacional del Trabajo. https://www.insst.es/documents/94886/161971/Cap%C3%ADtulo+72.+Industria+del+papel+y+de+la+pasta+de+papel.

Finklea, Jhon, Georges Coppée, Vilma Hunt, Richard Kraus, Wolfgang Lauring, Jacqueline Messite, Steven Sauter et al. 1998b. "Petróleo y Gas Natural" [Oil and Natural Gas]. In *In the Encyclopedia of Occupational Health and Safety*, edited by Richard S. Kraus, 78. Ginebra: Oficina Internacional del Trabajo. https://www.jmcprl.net/OIT%20completa/78.pdf.

Fundación Entorno Empresa y Medio Ambiente. 1998. "Informe Medioambiental Del Sector Artes Graficas" [Environmental Report of the Graphic Arts Sectors]. https://studylib.es/doc/8220643/informe-medioambiental-del-sector-artes-graficas.

Garmendia, Alfonso, Adela Salvador, Cristina Crespo, and Luis Garmendia. 2005. *Evaluacion de Impacto Ambiental* [Environmental Impact Assessment]. Madrid: Pearson Prentice Hall. https://www.pearsoneducacion.net/espa%C3%B1a/TiendaOnline/evaluacion-de-impacto-ambiental.

Geyer, Roland, Jenna Jambeck, and Kara Law. 2017. "Production, Use, and Fate of All Plastics Ever Made." *Science Advances* 3 (7): 1. https://www.science.org/doi/10.1126/sciadv.1700782.

Gioza Zuazua, Noemí, and Mariana Fernández Massi. 2017. "La Encuesta Nacional de Dinámica de Empleo e Innovación (ENDEI)" [Employment and Innovation Dynamics National Survey (ENDEI)]. United Nations CEPAL. https://repositorio.cepal.org/bitstream/handle/11362/44143/S1700839_es.pdf?sequence=1.

Gómez, Jose. 2016. "Diagnóstico Del Impacto Del Plástico—Botellas Sobre El Medio Ambiente: Un Estado Del Arte" [Impact Diagnosis of Plastic Bottles on the Environment: State of the Art]. Bachelor's Degree thesis, Universidad Santo Tomás. https://repository.usta.edu.co/handle/11634/10047.

Greenpeace México. n.d. "El Papel y Su Impacto Ambiental" [Paper and Its Environmental Impact]. Accessed March 25, 2022. https://archivo.estepais.com/inicio/historicos/94/14_Medio%20ambiente_El%20papel_greenpeace.pdf.

Hortal, Mercedes, Jorge León, Antonio Dobón, and David Moya. 2018. "Impactos ambiental derivados de las operaciones de transporte de papel para reciclar con destino a China" [Environmental Impacts from the Transportation of Paper for Recycling to China]. Fundación Mapfre. https://documentacion.fundacionmapfre.org/documentacion/publico/pt/bib/137360.do.

ICEX España Exportación e Inversiones. 2018. "Plástico en México" [Plastic in Mexico]. https://www.icex.es/icex/GetDocumento?dDocName=DOC2019826983&urlNoAcceso=/icex/es/registro/iniciar-sesion/index.html?urlDestino=https://www.icex.es:443/icex/es/navegacion-principal/todos-nuestros-servicios/informacion-de-mercados/sectores/industria-y-tecnologia/documentos/DOC2019826983.html&site=icexES.

International Organization for Standardization. 2016. "Perspectiva de ciclo de vida—lo que incluye la ISO 14001" [Life Cycle Perspective—Including ISO 14001]. https://cmdcertification.com/wp-content/uploads/2019/08/Perspectiva-de-ciclo-de-vida-ISO-14001.pdf.

Jin, Kaiyan, Yanjun Tang, Jichun Liu, Junming Wang, and Chunjie Ye. 2021. "Nanofibrillated Cellulose as Coating Agent for Food Packaging Paper." *International Journal of Biological Macromolecules* 168: 331–338. https://doi.org/10.1016/j.ijbiomac.2020.12.066.

Kim, Joo-Hyung, Bong Sup Shim, Heung Soo Kim, Young-Jun Lee, Seung-Ki Min, Daseul Jang, Zafar Abas, and Jaehwan Kim. 2015. "Review of Nanocellulose for Sustainable Future Materials." *International Journal of Precision Engineering and Manufacturing-Green Technology* 2 (2): 197–213. https://doi.org/10.1007/s40684-015-0024-9.

Kumar, Rakesh, Anurag Verma, Arkajyoti Shome, Rama Sinha, Srishti Sinha, Prakash Kumar Jha, Ritesh Kumar, et al. 2021. "Impacts of Plastic Pollution on Ecosystem Services, Sustainable Development Goals, and Need to Focus on Circular Economy and Policy Interventions." *Sustainability* 13 (17): 9963. https://doi.org/10.3390/su13179963.

Labeaga Viteri, Aitziber. 2018. "Polímeros biodegradables. Importancia y potenciales aplicaciones" [Biodegradable Polymers. Importance and Potential Applications]. Master's thesis, Universidad Nacional de Educación a Distancia. http://e-spacio.uned.es/fez/eserv/bibliuned:master-Ciencias-CyTQ-Alabeaga/Labeaga_Viteri_Aitziber_TFM.pdf.

Lopattananon, Natinee, Kuljanee Panawarangkul, Kannika Sahakaro, and Bryan Ellis. 2006. "Performance of Pineapple Leaf Fiber-Natural Rubber Composites: The Effect of Fiber Surface Treatments." *Journal of Applied Polymer Science* 102 (2): 1974–1984. https://doi.org/10.1002/app.24584.

López Sardi, Estela Mónica. 2007. "Fabricación de pasta de celulosa Aspectos técnicos y contaminación Ambiental" [Manufacturing of Cellullose Paste. Technical Aspects and Environmental Pollution]. Universidad de Palermo. https://www.palermo.edu/ingenieria/downloads/CyT6/6CyT%2005.pdf.

Martín, Ana. 2019. "Celulosa nanofibrilada y su aplicación en la industria papelera para la mejora de productos reciclados" [Nanofibrillated Cellulose and Its Application in the Paper Industry to Improve Recycled Products]. PhD thesis, Universidad Complutense de Madrid. https://eprints.ucm.es/id/eprint/51702/.

Méndez Prieto, Adrián. 2019. "Empaques flexibles multicapa, consideraciones técnicas" [Multilayer Flexible Packaging, Technical Considerations]. Plastics Technology. https://www.pt-mexico.com/articulos/empaques-flexibles-multicapa-consideraciones-tecnicas.

Miao, Xiaran, Jinyou Lin, and Fenggang Bian. 2020. "Utilization of Discarded Crop Straw to Produce Cellulose Nanofibrils and Their Assemblies." *Journal of Bioresources and Bioproducts* 5 (1): 26–36. https://www.sciencedirect.com/science/article/pii/S2369969820300530.

New ISO 14001:2015. 2019. "El papel del reciclaje en un Sistema de Gestión Ambiental" [The Role of Recycling in an Environmental Management System]. https://www.nueva-iso-14001.com/2019/05/reciclaje-en-un-sistema-de-gestion-ambiental/.

OEFA (Organismo de Evaluación y Fiscalización Ambiental). 2013. "Metodología para la estimación del riesgo ambiental" [Form to Estimate the Environmental Risk]. https://www.oefa.gob.pe/metodologia-para-la-estimacion-del-riesgo-ambiental/.

Opemed. 2020. "El (complejo) proceso del reciclaje del plástico" [The (Complex) Process of Plastic Recycling]. http://gestionderesiduosonline.com/el-complejo-proceso-del-reciclaje-del-plastico/.

Ortega Leyva, María Natalia. 2020. "Plástico, packaging y Economía circular en tiempos del COVID-19" [Plastic, Packaging and Circular Economy during COVID-19]. Plastics Technology. https://www.pt-mexico.com/articulos/plastico-packaging-y-economia-circular-en-tiempos-del-covid-19.

Otto, Sarah, Mara Strenger, Andrea Maier-Nöth, and Markus Schmid. 2020. "Food Packaging and Sustainability—Consumer Perception vs. Correlated Scientific Facts: A Review." *Journal of Cleaner Production* 298: 9. https://doi.org/10.1016/j.jclepro.2021.126733.

Packsys Academy. 2012. "¿Qué es el Polipropileno Biorentado (BOPP)?" [What Is Biorented Polypropylene (BOPP)?]. http://www.blog.packsys.com/bopp/.

Plastic Collectors. 2020. "¿Cómo se hace el plástico? Proceso de producción de plástico simplificado" [How Is Plastic Made? Plastic Production Process Simplified]. https://www.plasticcollectors.com/es/blog/how-is-plastic-made/.

Reciclajes Avi. 2015. "¿Sabes cuántos años tardan en degradarse el cartón, el plástico o el vidrio?" [Do You Know How Many Years It Takes for Cardboard, Plastic or Glass to Degrade?]. http://reciclajesavi.es/sabes-cuantos-anos-tardan-en-degradarse-el-carton-el-plastico-o-el-vidrio/.

Santos, A. S. F., B. A. N. Teixeira, J. A. M. Agnelli, and S. Manrich. 2005. "Characterization of Effluents through a Typical Plastic Recycling Process: An Evaluation of Cleaning Performance and Environmental Pollution." *Resources, Conservation and Recycling* 45 (2): 159–171. https://doi.org/10.1016/j.resconrec.2005.01.011.

Sanz Tejedor, Ascensión. n.d. "Tecnología de la celulosa. La industria papelera" [Pulp Technology. The Paper Industry]. *Química Orgánica Industrial*. Accessed June 1, 2021. https://www.eii.uva.es/organica/qoi/tema-03.php.

Sbarbati Nudelman, Norma. 2020. *Residuos Plásticos en Argentina. Su impacto ambiental y en el Desafío de la Economía Circular* [Plastic Residues in Argentina. Its Impact on the Environment and on the Development of Circular Economy]. Buenos Aires: Academia Nacional de Ciencias Exactas, Físicas y Naturales. https://cairplas.org.ar/2016/wp-content/uploads/2020/12/Residuos-plasticos-final-1.pdf.

Socas González, María de los Ángeles. 2018. "Contaminación por residuos: Islas de plástico" [Waste Pollution: Plastic Patches]. Bachelor's Degree thesis, Universidad de La Laguna. https://riull.ull.es/xmlui/bitstream/handle/915/13438/CONTAMINACION%20POR%20RESIDUOSISLAS%20DE%20PLASTICO.pdf?sequence=1&isAllowed=y.

Sociedad Argentina de Pediatría. n.d. "Las deforestaciones en el mundo y el impacto en la salud" [Deforestation in the World and Its Impact on Health]. Accessed March 24, 2021. https://www.sap.org.ar/uploads/archivos/general/files_deforestacion_1566991482.pdf.

Strubinger, Adelitza, Fernando Morales, and Keysler Aponte. 2014. "Riesgo Ambiental y uso de catalizador gastado de fcc en mezclas de morteros" [Environmental Risk and Use of FCC Spent Catalyst in Mortar Mix]. *Journal of the School of Engineering at Universidad Centra de Venezuela* 29 (4): 1–14. http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0798-40652014000400009.

Tangri, Neil. 2005. *Incineración de residuos: una tecnología muriendo* [Waste Incineration: a Dying Technology]. Buenos Aires: Alianza Global para Alternativas a la Incineración.

https://www2.congreso.gob.pe/sicr/cendocbib/con4_uibd.nsf/BEED4EBCBF98D22E05257D690071A2E9/$FILE/IncineracionResiduosTecnolog%C3%ADaMuriendo.pdf.

Tecnología del Plástico. 2018. “8 problemas comunes en extrusión y sus posibles soluciones” [8 Common Problems in Extrusion and Their Possible Solutions]. https://www.plastico.com/temas/8-problemas-comunes-en-extrusion-y-sus-posibles-soluciones+123975.

Tiseo, Ian. 2021. “Global Plastic Production by Industrial Sector 2017”. Statista. https://www.statista.com/statistics/1134796/plastic-production-by-industrial-sector-worldwide/.

Torres Fuica, Gabriela. 2017. “Impacto ambiental de la Industria de Celulosa en Chile” [Environmental Impact of the Cellulose Industry in Chile]. Thesis, Universidad de Concepción. http://www2.udec.cl/~gtorresf/documentos/informe.pdf.

Tosar, Pablo. n.d. “Materiales usados en envases flexibles para alimentos” [Materials Used in Flexible Food Packaging]. Accessed March 24, 2021. http://www.ciu.com.uy/innovaportal/file/85294/1/presentacion-ctplas---compania-azul--version-para-distribuir.pdf.

United Nations. 2018. “Cambio Climático y medioambiente” [Climate Change and Environment]. https://news.un.org/es/story/2018/06/1435111.

United Nations Brundtland Commission. 1987. “Report of the World Commission on Environment and Development: Our Common Future.” http://www.un-documents.net/our-common-future.pdf.

United Nations Conference on Trade and Development. 2021. “El comercio mundial de plásticos es un 40% mayor de lo que se pensaba, según un estudio” [Global Plastics Trade 40% Higher than Previously Thought, Study Finds]. https://unctad.org/es/news/el-comercio-mundial-de-plasticos-es-un-40-mayor-de-lo-que-se-pensaba-segun-un-estudio.

U.S. Environmental Protection Agency. n.d. “Orígenes y consecuencias de la basura acuática” [Origins and Consequences of Aquatic Litter]. Accessed June 2, 2021. https://espanol.epa.gov/espanol/origenes-y-consecuencias-de-la-basura-acuatica.

Vargas-Isaza, Carlos Andrés, Juan Carlos Posada-Correa, Leyla Yamile Jaramillo-Zapata, and Luis Alberto García. 2015. “Consumos de energía en la industria del plástico: revisión de estudios realizados” [Energy Consumption in Plastic Industry—Review of Studies Developed]. *CEA Journal* 1 (1): 1–15. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3520287.

World Economic Forum. 2021. “Future of Reusable Consumption Models.” https://es.weforum.org/reports?utf8=%E2%9C%93&query=plastic.

Zabaniotou, A., and E. Kassidi. 2003. “Life Cycle Assessment Applied to Egg Packaging Made from Polystyrene and Recycled Paper.” *Journal of Cleaner Production* 11 (5): 549–559. https://doi.org/10.1016/S0959-6526(02)00076-8.

Zero Emissions Objetive (Z.E.O.) 2020. “¿Cuánto CO2 emite el plástico?” [How Much CO2 Does Plastic Emit?]. https://plataformazeo.com/es/cuanto-co2-emite-el-plastico/.

ABOUT THE AUTHORS

Nathalie Katherine Bittrich Vargas: Bachelor in Industrial Engineering, Carrera de Ingeniería Industrial, Universidad de Lima, Carrera de Ingeniería Industrial, Lima, Peru

Marcela Ines Ruiz Mogollón: Bachelor in Industrial Engineering, Carrera de Ingeniería Industrial, Universidad de Lima, Carrera de Ingeniería Industrial,, Lima, Peru

Rosa Patricia Larios-Francia: Research Professor, Carrera de Ingeniería Industrial, Universidad de Lima, Carrera de Ingeniería Industrial, Lima, Peru

The International Journal of Environmental Sustainability is one of three thematically focused journals in the family of journals that support the Sustainability Research Network—its journals, book imprint, conference, and online community. The journal focuses on sustainable ecosystems, urban environments, agriculture, energy systems, water use, atmospheric quality, and biodiversity.

In addition to traditional, scholarly articles, this journal invites presentations of sustainability practices—including documentation of case studies and exegeses analyzing the effects of these practices.

The International Journal of Environmental Sustainability is a peer-reviewed, scholarly journal.

ISSN 2325-1077